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Next Meeting (Annual Business Meeting), Tuesday, May 18th.

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TRANSACTIONS

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OF

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1897

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 24, 1897.

The 114th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Duncan at 8.30 P. M.

PRESIDENT DUNCAN:—The Secretary will announce the ticket nominated by the Council at the meeting this afternoon.

THE SECRETARY:—From the nomination returns received from the membership, the Council has selected the following names which will be printed on the ballots for the guidance of members in their choice of candidates.

For President:

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RALPH W. POPE, of New York City.

The Council has decided to hold the General Meeting of the INSTITUTE at Greenacre-on-the-Piscataqua, Eliot, Maine, beginning on July 26th. This place was the residence of the late Moses G. Farmer, who was one of the charter members of the INSTITUTE and made an Honorary Member October 21st, 1890. He died at Chicago, May 25th, 1893, having been actively engaged in the preparation of his personal exhibit for the World's Fair. The date selected will be the 50th anniversary of Prof.

Farmer's relinquishment of teaching and the taking up of electrical work. Greenacre is beautifully situated on the east bank of the Piscataqua River, about ten miles beyond Portsmouth, N. H., and is reached in two hours from Boston.

The Annual Meeting for the election of officers, presentation of yearly reports, etc., will be held at 12 West 31st Street, as provided by the Constitution, on Tuesday, May 18th, which is the third Tuesday in the month.

The following Associate Members were elected at the meeting of the Council in the afternoon:

Name.	Address.	Endorsed by.
BECHTEL, ERNEST J.	Superintendent, Power Plant, Toledo Traction Co., Toledo, O.	E. S. Reid. W. E. Harrington. R. W. Pope.
FORD, ARTHUR HILLYER.	Fellow in Electrical Engineering, University of Wisconsin, Madison, Wis.	J. E. Davies, D. C. Jackson. S. B. Fortenbaugh.
HOLBROW, HERMAN L.	With New York Telephone Co., New York City, residence Rutherford, N. J.	S. B. Austin. H. F. Thurber. W. M. Petty.
KELLY, WILLIAM F.	Student in Expert Course, Fort Wayne Electric Corporation, Fort Wayne, Ind.	F. S. Hunting. E. A. Barnes. A. L. Hadley.

Total 4.

THE PRESIDENT:—The paper to be read this evening is on "The Influence of Heat Treatment Upon the Magnetic Properties of Steel and Iron," by Dr. K. E. Guthe. The paper will be presented by Professor Carhart, whom we all know.

Professor Carhart then read the following paper:

A paper presented at the 112th meeting of the American Institute of Electrical Engineers, New York, March 24th, 1897, President Duncan in the chair.

THE INFLUENCE OF HEAT TREATMENT UPON THE MAGNETIC PROPERTIES OF STEEL AND IRON.

BY DR. K. E. GUTHE.

Steel and iron, when heated to high temperatures, show a decided change in their magnetic properties. The earlier investigations[1] have shown, that in general the temporary induction in iron and steel rods increases with increase of temperature. G. Wiedemann[2] found that very hard steel rods show at 100° a larger temporary magnetic moment than at 0°, soft rods a larger magnetic moment at 0° than at 100° for the same magnetizing force, after they had been repeatedly heated and cooled. Rowland[3] showed that a rise of temperature causes an increase of induction, if the magnetizing force is small, but a diminution of induction if the magnetizing force is large. The same was observed by J. Hopkinson,[4] who undertook a great number of experiments in this line, especially in order to show the relation between the critical temperature, at which iron ceases to be magnetic, and the recalescence, first discovered by Barrett. According to the former, recalescence occurs at the critical temperature. Osmond, who distinguishes three points of recalescence for soft steel, places the critical temperature at the second point of recalescence. Tomlinson's[5] and Kunz's[6] experiments show also the change in magnetic properties due to a rise of temperature.

1. Wiedemann's "Electricität," 2d ed., III., p. 848–860.
2. G. Wiedemann. *Pogg. Ann.* 129, 346, 1864.
3. Rowland. *Phil. Mag.* (4), 48, 321, 1874.
4. Hopkinson, *Phil. Trans.*, 180 A, 443, 1889. *Proc. Roy. Soc.*, 48, 443, 1890.
5. Tomlinson. *Phil. Mag.* (5), 25, 372, 1888.
6. Program Gymnasium zu Darmstadt, 1893.

After steel has been heated beyond recalescence and is suddenly quenched in cold water, the mechanical hardening is accompanied by a corresponding magnetic hardening, *i. e.*, the permeability decreases and the hysteresis loss increases greatly. This influence of hardening is well known, and was first thoroughly investigated by Ewing.[1] Very little is known about the influence of heat treatment on such hardened steel. Barus and Strouhal,[2] in an exhaustive paper, show the influence of tempering on the retentivity of steel magnets, and are the originators of the well-known method of seasoning magnets by subjecting them for several hours to a temperature of 100°, which method has recently been used very successfully by B. O. Pierce. Their results, as far as they have a bearing on the present research, are, (1) that the magnetic moment of a hardened steel magnet is smaller after reheating to about 100° than it was before, and that on heating to still higher temperatures it increases again; (2) that the length of time during which the bars have been at the high temperature is of some influence, especially for the lower temperatures. The present work was undertaken with a view of following the annealing process step by step, and obtaining the relations between the magnetizing force, maximum induction, remanence and coercive force for each of these steps. The results are also interesting from a theoretical point of view, since they show a decided difference in the rate of change of the magnetic properties for the different temperatures.

Description of the Method.—The rings were all of the same form, *i. e.*, hoops with an average diameter of 12.6 cm. and a thickness of only 8 mm. The diameters were measured by vernier calipers and the cross-section was found by dividing the volume, which was determined by the loss of weight in water, by the average circumference. New measurements were taken every time after the rings had been subjected to a temperature higher than 600°. They were wound with bicycle tape, and on this the primary coil. Before each experiment the insulation was carefully tested. Rowland's ballistic method was employed. Instead of the usual way of finding the constant of the galvanometer by means of an earth-coil, I charged and discharged a standard condenser through the galvanometer (see Carhart and

1. Ewing. *Phil. Trans.*, 547, 1885, or Ewing, "Magnetic Induction," etc., p. 82.

2. "U. S. Geological Survey," No. 14, 1885.

Patterson's "Electrical Measurements"). The equations used will then be

$$\mathfrak{B} = \frac{d_2\, C\, E\, r}{d_1\, n_2} \frac{100}{A}$$

where

$\mathfrak{B}$ = the increase in induction,
d_2 = the deflection due to the change of the magnetic flux through one square centimetre of the ring,
C = the capacity of the standard condenser expressed in microfarads (= .2 microf.),
E = the *E. M. F.* of the Carhart-Clark cell in volts,
r = the total resistance of the secondary circuit,
d_1 = the deflection obtained by the discharge of the condenser,
n_2 = the number of secondary turns around the ring, which was equal to 30 in every case,
A = the cross-section of the ring.

and

$$\mathfrak{H} = \frac{4\,\pi\, n_1}{10\, L} \mathrm{I}$$

where

$\mathfrak{H}$ = the magnetizing force,
n_1 = the number of primary turns on the ring,
I = the magnetizing current expressed in amperes,
L = the average circumference.

The deflection due to the discharge of the condenser was taken on open circuit. This produces an error in the constant. An independent experiment showed that the value obtained is 1.50 per cent. too large. In order to obtain the absolute values for $\mathfrak{B}$ in the following tables, the data should be multiplied by .985. In order to eliminate the error due to the creeping up of the induction, the steps taken were as nearly as possible the same for the same ring at different stages of the treatment. I believe the total errors of observation to lie within .5 per cent. The experiments at each step for each ring consisted in the determination of the hysteresis curves for a number (8-10) of different magnetizing forces, the largest in every case being between 60 and 65. In the final results I give the hysteresis curves for the largest values of $\mathfrak{H}$ only. The magnetizing curves were taken, but they are not given under the following results, since, as Hopkinson has shown, this curve for virgin steel differs appreciably from one taken with a ring previously magnetized. It was thought

to be of more importance to represent the curves for $\mathfrak{B}_m$ and $\mathfrak{B}_r$ as functions of the maximum magnetizing force. (See Fig. 4.). Moreover, it was possible to show the influence of the reheating upon Houston and Kennelly's law,[1] *i. e.*, that for small magnetizing forces the remanence ($\mathfrak{B}_r$) is a linear function of the maximum induction ($\mathfrak{B}_m$). These two values, $\mathfrak{B}_m$ and $\mathfrak{B}_r$, are plotted on Fig. 5, and these curves are of great interest, showing the range through which this law holds good in the different stages of the heating process, and what variations in the constants are produced by the tempering.

Chemical Analysis.—the chemical analysis of the rings gave the following results:

	Ring I. Crescent Steel.	Ring II. Basic Steel.	Ring III. Very Soft Steel.	Ring IV. Swedish Iron.
Carbon	.868%	.309%	.0755%	.144%
Silicon	.234	.025	.0155	.0624
Sulphur	trace	.059	.0645	.015
Phosphorus	.0172	.146	.124	.018
Manganese	.27	.78	.36	trace

For the chemical analysis and the heat treatment of the rings, I am greatly indebted to Prof. E. D. Campbell, director of the metallurgical laboratory, and his assistant, Mr. A. R. Miller. I gladly express my deep obligations to them, especially to Professor Campbell, who devised and superintended every particular of the complete heat treatment.

The rings were first heated in the original state and then subjected to the heat treatment. The different steps taken are the following:

A. Rings in the original state.

B. Heated to about 670° and quenched.

C. Heated to a little over 900° and quenched.

The hardened rings were then tempered by reheating to the temperatures indicated below, and then allowed to cool slowly. D, 100° for one hour; E and F, 100° for 24 hours; G, 200°; H, 300°; I, 450°; K, 800°; L (only for Rings II. and III.), about 950°.

Results.

A. Rings in the original state.

1. *Electrical World*, 25, 681, 1895.

The measurements of rings gave the following data:

	Ring I.	Ring II.	Ring III.	Ring IV.
Mean diameter.....	12.607 cm.	12.699 cm.	12.68 cm.	12.607 cm.
Volume	95.099 cm³	80.687 cm³	109.29 cm³	107.99 cm³
Cross-section.....	2.401 cm²	2.021 cm²	2.754 cm²	2.737 cm²

As I stated before, these measurements were repeated every time after the rings had been subjected to a high temperature, so after the following steps: B, C, K and L. Each time a small decrease of the cross-section was observed.

In the original state, the hysteresis curves for only one maximum magnetizing field ($\mathfrak{H}$) of about 60 were determined, except for Ring I, for which the value of $\mathfrak{H}$ was varied. In the following tables n_1 designates the number of primary turns, c the deflection of the galvanometer, obtained by the discharge of a capacity equal to .2 microfarad charged by a Carhart-Clark standard cell, d the deflection of the galvanometer due to the change of the lines of magnetic force in the ring, $\mathfrak{B}$ the calculated value of the induction, I the current in the primary measured in amperes, $\mathfrak{H}$ the value of the magnetizing force.

It will be noticed that I give only the values of $\mathfrak{B}$ and $\mathfrak{H}$ for one side of the hysteresis curves. Since the same steps were taken on the ascending and descending branch of the loop, the values were generally identical, and are therefore not recorded in the following tables, though the whole cycle was taken in the actual experiments:

A. Before Heating.

TABLE I.

Ring I; $n_1 = 298$; const. $= 141.5$; $\mathfrak{B} = 18.7 \times d$; $\mathfrak{H} = 9.45\ I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+7966	0	0
48	7096	.270	2.55
14	6807	.350	3.31
47	5928	.538	5.09
64	4731	.705	6.67
184	1990	.940	8.89
107	−2304	1.210	11.44
102	5984	1.7	16.07
88	7630	2.09	19.76
87	9257	2.66	25.15
207	11257	3.86	36.50
63	12436	4.9	46.33
73	13838	6.5	61.46
47	12959	4.1	38.76
69	11609	2.1	19.86
88	10023	.86	8.13
110	7066	0	0

TABLE II.

Ring II; $n_1 = 292$; const. $= 141.5$; $\mathfrak{B} = 22.2 \times d$; $\mathfrak{H} = 9.39\ I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+8303	0	0
112	5810	.16	1.5
262	0	.285	2.7
137	−3041	.399	3.7
101	5984	.538	5.0
79	7037	.705	6.6
73	8092	.94	8.8
57	9023	1.21	11.3
66	11380	1.70	16.0
68	12898	2.70	25.2
41	13808	3.90	36.2
28	14430	4.90	45.9
29	15074	6.85	64.4
19	14632	4.80	45.0
44	13653	2.25	21.1
85	11766	.70	6.6
90	11192	.49	4.6
190	8258	0	0

TABLE III

Ring III: $n_1 = 304$; const. $= 141.5$; $\mathfrak{B} = 16.3d$; $\mathfrak{H} = 9.63 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+9568	0	0
93	8052	.16	1.54
154	5542	.285	2.74
288	848	.36	3.47
107	— 880	.344	3.79
202	4173	.48	4.62
134	6357	.58	5.59
115	8 32	.713	6 87
105	9943	.93	8.96
75	11166	1.19	11.45
77	12421	1.6	15.41
74	13627	2.6	25.04
21	13969	3.2	30.82
49	14768	4.75	45.74
32	15289	6.7	64.52
40	14621	3.75	36.11
41	13953	2.00	19.26
49	13154	1.1	10.59
27	12714	.80	7.70
52	11866	.45	4.33
141	9568	0	0

TABLE IV.

Ring IV; $n_1 = 291$; $c = 141.5$; $\mathfrak{B} = 16.3 \times d$; $\mathfrak{H} = 9.23 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+6600	0	0
155	4042	.08	.7
322	—1270	.165	1.5
225	4083	.298	2.75
185	8036	.410	3.8
55	8943	.558	5.2
54	9844	.731	6.75
40	10643	.973	8.98
35	11220	1.248	11.5
39	11864	1.78	16.4
40	12524	2.78	25.7
97	13069	3.98	36.7
44	13695	6.60	60 9
34	13134	4.0	36 9
38	12507	2.11	19.5
60	11517	.9	8 3
59	10544	.5	4.6
20	10214	4	3.7
219	6600	0	0

B. Heated to 675° and Quenched.

TABLE V.

Ring I; $n_1 = 298$; $c = 135.5$; $\mathfrak{B} = 19.5 \times d$; $\mathfrak{H} = 9.46 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+7283	0	0
20.	6893	.3	2.84
9.	6718	.4	3.78
19.5	6474	.58	5.2
17.5	6133	.72	6.81
29	5567	1.00	9.5
105.5	3510	1.42	13 4
201.	— 410	2.15	20.3
128.	2886	2.72	25.7
206.	6903	4.0	37.8
195.	9341	5.10	48.2
116.	11603	7.10	67.2
51.	10608	4.15	39.3
58.	9477	2.18	20.6
30.	8717	1.21	11.4
36.5	8005	.58	5.49
37.	7283	0	0

TABLE VI.

Ring II: $n_1 = 292$; $c = 135.5$; $\mathfrak{B} = 23d$; $\mathfrak{H} = 9.39 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+6925	0	0
46.5	5842	.13	1.2
164.	9021	.28	2.6
125.	— 892	.40	3.7
94.	3082	.55	5.2
79.	4923	.70	6.6
74.	6647	.95	8.9
94.	8837	1.42	13.3
78.	10654	2.10	19.7
45.5	11714	2.68	25.2
67.	13275	3.90	36.6
42.5	14265	5.00	47.0
48.	15383	7.08	66.5
52.	14171	4 10	38.5
77.	12377	2.15	20.2
93.	10210	.85	8.0
49.	9068	.45	4.2
54.	7810	.18	1.7
38.	6925	0	0

TABLE VII.

Ring III $n_3 = 304$; $c = 135.5$, $\mathfrak{B} = 17.0 \times d$; $\mathfrak{H} = 9.58 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+6956	0	0
76	5660	.13	1.2
104	3887	.20	1.9
247	— 324	.28	2.7
135	2066	.40	3.8
127	5131	.52	5.0
95	6731	.70	6.7
80	8115	.95	9.1
97	9769	1.40	13.4
85	11218	2.05	19 6
53	12121	2 60	24 9
81	13502	3.75	35.9
50	14371	4.75	45.5
57	15343	6.50	62.3
65	14236	3.90	37.4
102	12497	2.08	19 9
128	10315	.85	8.14
67	9173	.45	4.3
40	8491	.30	2.9
33	7828	.18	1.7
57	6956	0	0

TABLE VIII.

Ring IV; $n_4 = 991$; $c = 135.5$; $\mathfrak{B} = 17.2 \times d$; $\mathfrak{H} = 9.24 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+4610	0	0
108	2752	.07	.63
194	— 585	.15	1.39
134	2800	.20	1.85
90	4438	.30	2.77
79	5797	.40	3.70
68	6967	.55	5.08
57	7947	.72	6.65
57	8927	1.00	9 24
86	10406	1.45	13.4
83	11834	2.18	20.1
50	12694	2.75	25.4
65.5	13821	4.00	37.0
34	14406	5.10	47.1
37	15042	7.05	66.1
40	14198	4.2	38.8
97	12530	2.2	20.3
152	9916	.90	8.32
87.5	8411	.48	4.44
114	6450	.18	1.66
107	4610	0	0

TABLE IX.

Ring I.			Ring II.			Ring III.			Ring IV.		
$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$
11603	7283	67.2	15383	6925	66.5	15343	6956	62.3	15042	4610	66.1
8444	5343	35.2	13339	6839	36.6	13871	6913	35.5	14035	4816	35.1
5222	3136	24.1	10818	6454	19.5	11976	6683	19 6	10630	4747	13.7
3783	2165	19.0	9204	5951	13.3	8336	5813	9.1	9133	4592	9.24
1833	819	13.2	7386	5103	8.9	5950	4364	5.0	8273	4489	6.93
527	98	6.3	2318	1526	2.6	4705	3427	3 8	6347	4283	3.70
			594	221	1.7	3401	2412	2.7	3870	2563	1 85
			4098	3530	5.2	1884	1091	1.9	1514	310	.46
			3012	2340	3.7						

C. Heated to 900° and Quenched.

TABLE X.

Ring I; $n_1 = 305$; $c = 115$; $\mathfrak{B} = 22.9 \times d$; $\mathfrak{H} = 9.68 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+3786	0	0
19.	3351	.66	6.39
6.5	3202	.87	8.42
14.5	2870	1.3	12.6
23.	2344	1.9	18.4
29.	1841	2.32	22.5
66.	331	3.30	31.9
93.	—1707	4.15	40.2
47.	2872	4.52	43 8
87.	4862	5.50	53.2
81.	6715	6.90	66.8
43.	5731	4.00	38.7
36.	4907	2.08	20.1
32.	4173	.65	6.29
17.	3786	0	0

TABLE XI.

Ring II; $n_2 = 292$; $c = 116$; $\mathfrak{B} = 27.4 \times d$; $\mathfrak{H} = 9.19 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+8876	0	0
27	8135	.38	3.49
13	7778	.50	4.59
20	7299	.65	5.97
44	6092	.90	8.17
171	1302	1.38	12.68
169	—3336	2.00	18.38
100	6080	2.55	23.43
143	10004	3.70	34.00
62	11705	4.75	43 65
57	13269	6.70	61.6
36	12981	3 90	35.8
54	10799	1.60	14.7
31	9048	.75	6.89
39	8878	0	0

TABLE XII.

Ring III; $n_1 = 300$; $c = 115$; $\mathfrak{G} = 20.3 \times d$; $\mathfrak{H} = 9.53 \times I$.

d	$\mathfrak{G}$	I	$\mathfrak{H}$
—	+8993	0	0
23	8526	.12	1.14
39	7734	.25	2.32
43	6851	.38	3.62
122	4384	.50	4.76
210	121	.65	6.2
166	−3249	.90	8.58
192	7146	1.38	13.15
135	9886	2.00	19.06
69	11287	2 52	24 02
89	13093	3.60	34 30
54	14189	4.65	44.31
66	15529	6.40	61.00
58	14352	3.80	36.21
102	12281	1 60	15.25
66	10941	.75	7 15
34	10251	.40	3.81
62	8992	0	0

TABLE XIII.

Ring IV: $n_1 = 275$; $c = 122$; $\mathfrak{G} = 19.3 \times d$; $\mathfrak{H} = 8.73 \times I$.

d	$\mathfrak{G}$	I	$\mathfrak{H}$
—	+4622	0.	0.
94	2808	.072	.63
162	− 319	.125	1.09
122	2672	.195	1 70
83	4275	.268	2.34
71	5645	.368	3.21
59	6784	.495	4 32
51	7768	.660	5 76
52	8772	.865	7.55
75	10219	1.28	11.2
68	11531	1.82	15.9
39	12284	2.25	19.6
54	13326	3.60	31.4
32	13944	4.60	40.1
35	14619	6.30	55.0
44	13770	3.88	33 9
120	11454	1 58	13 8
104	9447	.75	6.55
66	8173	.42	3.67
105	6147	.122	1.07
79	4622	0.	0.

TABLE XIV.

Ring I.			Ring II.			Ring III.			Ring IV.		
$\mathfrak{G}_m$	$\mathfrak{G}_r$	$\mathfrak{H}$	$\mathfrak{G}_m$	$\mathfrak{G}_r$	$\mathfrak{H}$	$\mathfrak{G}_m$	$\mathfrak{G}_r$	$\mathfrak{H}$	$\mathfrak{G}_m$	$\mathfrak{G}_r$	$\mathfrak{H}$
6715	3786	66.8	13268	8875	61.6	15529	8993	61.0	14629	4632	55.0
5193	2700	53.2	11731	8219	43.7	14180	8821	44.3	13510	4825	32.0
3580	1453	44.3	10991	7300	33.8	13134	8648	34.6	11696	4786	17.5
1992	480	31.9	7684	5434	23.0	11784	8313	24.0	8850	4584	7.94
927	114	18.4	6216	4212	18.2	10343	7460	19.1	6929	4053	4.52
389	93	8.6	3818	2401	12.1	8292	6161	13.15	4883	3146	2.36
207	3	3.0	1825	919	8.09	6029	4486	8.58	2470	1602	1.07
			933	306	5.97	4273	2974	6.2	1038	546	.63
			370	69	3.40	2090	1695	4.76			
						1238	648	3 8			
						650	203	2.32			
						264	41	1.72			

D. Temperature for One Hour at 100°.

TABLE XV.

Ring I; $n_1 = 305$; $c = 147$; $\mathfrak{G} = 17.9 \times d$; $\mathfrak{H} = 9.68 \times I$.

d	$\mathfrak{G}$	I	$\mathfrak{H}$
—	+3714	0	0
42	2952	.985	9 53
27	2469	1.5	14 5
52	1538	2.3	22.3
65	374	3.06	29 6
80	−1165	3.70	35.8
141	3689	4.66	45.1
160	6543	6.5	62 9
14	6292	5.66	54.8
86	4753	1 9	18.4
25	4308	1.00	9.7
15	4037	.51	4.9
18	3715	0	0

TABLE XVI.

Ring II; $n_1 = 292$; $c = 119$; $\mathfrak{G} = 26.75 \times d$; $\mathfrak{H} = 9.19 \times I$.

d	$\mathfrak{G}$	I	$\mathfrak{H}$
—	+8719	0	0
45	7515	.331	4.88
23	6900	.703	6 46
52	5509	.938	8.62
180	694	1.414	13.00
171	−3880	2.09	19.20
99	6528	2.66	24.44
135	10139	3.93	36.12
58	11690	5.07	46.59
57	13215	7.2	66.17
38	12197	4.13	38.24
56	10699	1.65	15.16
96	10003	.832	7.64
20	9468	.488	4.48
28	8719	0	0

TABLE XVII.

Ring III; $n_1 = 300$; c 119; $\mathfrak{B} = 19.6 \times d$; $\mathfrak{H} = 9.53 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+8507	0	0
67	7174	.278	2 65
47	6253	.388	3.70
147	3372	.534	5 09
105	— 430	.707	6.74
155	3488	.940	8 96
183	7075	1.412	13.46
127	9564	2.08	19.82
65	10838	2.63	25 05
87	12543	3.83	36 51
52	13562	4.92	46.89
66	14856	6.9	65.75
59	13701	4.08	38.88
102	11702	1.66	15.50
51	10709	.935	8.92
43	9859	.492	4.69
69	8507	0	0

TABLE XVIII.

Rnig IV; $n_1 = 275$; $c = 136$; $\mathfrak{B} = 17.3 \times d$; $\mathfrak{H} = 8.73 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+4921	0	0
125.5	2750	.08	.70
152.	120	.129	1.13
144.	—2371	.200	1.75
97.	4049	.277	2.42
86.5	5345	.388	3.39
71.	6773	.532	4.64
60.	7811	.705	6.15
60.	8849	.938	8.19
87.	10354	1.410	12.31
80.	11738	2.10	18.33
46.	12534	2.65	23.13
63.	13624	3.88	33.87
34.	14212	5 00	34.65
38.	14869	7.01	61.20
48.	14038	4.11	35 9
129.	11806	1.67	14.6
148.	9246	.623	5.44
139.	6841	.174	1.52
111.	4921	0	0

TABLE XIX.

Ring I.			Ring II.			Ring III.			Ring IV.		
$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$
6543	3714	62.9	13215	8721	66.2	14857	8487	65.7	14868	4921	61.2
3813	1718	45.1	11690	8078	46.3	12573	8222	36.3	12568	4904	23.3
2542	788	35.9	10339	7303	35.8	9918	7174	19 8	10392	4794	12.35
1898	403	29.2	7944	5044	24.4	7987	5939	13.34	7923	4429	6.17
1235	179	22.3	6393	4440	19.2	5860	4371	8.92	5951	3702	3.40
734	72	14 7	4066	2675	12.56	4253	3077	7.00	3720	2457	1.75
292	14	6.56	1832	923	8 58	2675	1754	5.04	2405	1557	1.05
134	9	3.05	589	134	4.87	1215	568	3.65	1963	727	.72
			254	27	2.55	617	186	2.65			

G. Temperature at 200°.

TABLE XX.

Ring I; $n_1 = 292$; $c = 114$; $\mathfrak{B} = 23.1 \times d$; $\mathfrak{H} = 9.27 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+4662	0	0
17.5	4258	.515	4.78
5	4143	.685	6.35
9	3935	.915	8.48
20	3473	1.385	12.8
33	2711	2.05	19.
36	1880	2.60	24.1
136	—1258	3 8	35.2
246	4627	4 9	45.4
139	7834	6.9	64.0
44	6820	4.00	37.3
49.5	5690	1.60	14 8
26	5078	.612	5.67
18	4663	0	0

TABLE XXI.

Ring I.

$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$
7834	4662	64.0
5215	2665	45.4
3211	1205	35.2
1655	339	24.0
462	46	8.44
166	5	3.5

H. Tempered at 300.°

TABLE XXII.

Ring I; $n_1 = 300$; $c = 127$; $\mathfrak{B} = 20.7 \times d$; $\mathfrak{H} = 9.56 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+8931	0	0
63	7628	.922	8.81
43	6738	1.401	13.38
89	5041	2.09	19.98
127	2412	2.64	25 24
275	−3281	3.14	30.02
250	8455	3.79	36.2
134	11229	4.94	47.2
97	13237	6.95	66.4
38	12450	4.8	45.9
88	10698	1.76	16.8
82	8931	0	0

TABLE XXIII.

Ring II; $n_1 = 300$; $c = 129$; $\mathfrak{B} = 24.7 \times d$; $\mathfrak{H} = 9.44 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+9399	0	0
60	7916	.506	4.78
27	7249	.670	6.32
74	5491	.890	8.40
164	1370	1.155	11.13
242	−4607	1.62	15.10
127	7744	1.99	18.79
86	9868	2.49	23.5
85	11968	3.60	34.0
42	13005	4.62	43.6
48	14190	6.42	60.6
37	13276	3.8	35.9
72	11498	1.338	12.65
43	10436	.550	5.19
42	9399	0	0

TABLE XXIV.

Ring III; $n_1 = 295$; $c = 129$; $\mathfrak{B} = 18.1 \times d$; $\mathfrak{H} = 9.69 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+8905	0	0
58.	7855	.263	2.55
33.	7258	.370	3.58
66.	6063	.505	4.89
225.	1990	.670	6.49
226.	−2101	.890	8.62
255.	6717	1.352	13.08
161.	9631	2.00	19.4
73.	10059	2.55	24.7
93.	12635	3.72	36.0
56.5	13658	4 80	46.5
70.5	14934	6.78	65.7
59.	13866	3.92	38.0
125.	11603	1.34	13.0
72.	10300	.550	5.33
77.	8926	0	0

TABLE XXV.

Ring IV; $n_1 = 300$; $c = 128$; $\mathfrak{B} = 18.4 \times d$; $\mathfrak{H} = 9.52 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+5640	0	0
127.	3303	.077	.73
136.	433	.120	1.14
153.	−2382	.192	1.83
101.	4240	.267	2.54
90.	5806	.375	3.57
70.	7184	.510	4.86
61.	8306	.674	6.42
62.	9447	.897	8.54
87.	11048	1.355	12 9
73.	12391	2.00	19.0
38.	13090	2.51	23.9
44.5	13909	3.6	34 3
23.	14332	4.6	43.8
27.	14899	6.3	60.
32.5	14232	3.82	36.4
57.	13184	2.02	19.2
96.	11417	1.02	9 71
99.	9595	.49	4.66
111.	7553	.154	1.47
105.	5621	0	0

TABLE XXVI.

Ring I.			Ring II.			Ring III.			Ring IV.		
$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$
13237	8932	66.4	14190	9399	60.6	14934	8905	65.7	14830	5640	60.0
11168	7628	46 5	12029	8793	34.0	12679	8024	36.2	12402	5612	19.0
9656	6552	35.6	8506	6595	18.9	9909	7475	19.4	8409	5031	6.4
7214	4308	20.25	6793	5064	15.1	7702	6036	13.1	5101	3542	2.5
3926	1610	24.85	3940	2680	11.13	5190	3969	8.65	2511	1739	1.13
			2186	1223	8.4	3310	2367	6.5			
						1548	869	4.9			

I. Tempered at 450°.

TABLE XXVII.

Ring I; $n_1 = 300$; $c = 127$; $\mathfrak{B} = 20.7 \times d$; $\mathfrak{H} = 9.36 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+12198	0	0
37	11431	.513	4 92
15	11121	.676	6 44
26	10983	.900	8.6
87	8782	1.368	13.1
85	7022	1.62	15.5
95	5056	1 80	17 2
98	3027	1.89	18 1
250	−2143	2.00	19 1
211	6516	2.17	20.7
123	9062	2.38	22.5
94	11008	2.68	25 6
65	12359	3.22	30.8
69	13782	4.48	42 8
62	15065	7.00	66.9
69	13637	2.00	19.1
25	13119	1.015	9 7
44.5	12198	0	0

TABLE XXVIII.

Ring II; $n_1 = 300$; $c = 127$; $\mathfrak{B} = 25.1 \times d$; $\mathfrak{H} = 9.44 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+11207	0	0
88	8908	.51	4.81
34	7643	.673	6.35
163	3552	.895	8.45
130	389	1.011	9.53
145	−3351	1.157	10 9
133	6689	1.352	12.74
173	11031	2.00	18.88
57	12402	2.54	24.0
61	13993	3.65	34.46
31	14771	4.7	44.37
34	15624	6.49	61.3
98	14921	3 86	36.4
48	13716	1 6	15.1
36	12812	.754	7.12
64	11206	0	0

TABLE XXIX.

Ring III; $n_1 = 300$; $c = 127$; $\mathfrak{B} = 18.4 \times d$; $\mathfrak{H} \times 9.53 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+9890	0	0
36	9228	.136	1.3
112	7167	.373	3.55
220	3119	.51	4 86
200	− 561	.626	5.97
60	1665	.676	6.44
221	5731	.90	8 58
222	9816	1.368	13.1
123	12079	2.03	19.3
58	13146	2.6	24.8
75	14526	3.8	36.2
41	15280	4.88	46.5
42	16053	6.82	65.0
38	15354	4.02	38.3
93	13043	1.62	15.44
61	12521	.902	8.60
57	11472	.459	4 37
86	9890	0	0

TABLE XXX.

Ring IV; $n_1 = 300$; $c = 126$; $\mathfrak{B} = 18.7 \times d$; $\mathfrak{H} = 9.52 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+6189	0	0
130	3590	.078	74
175	318	.120	1.14
175	−2054	.190	1.81
112	5040	.262	2 49
102	6356	.375	3.57
76	8377	.570	5.43
66	9611	.673	6.41
66	10845	.896	8.53
79	12322	1.35	12.85
46	13182	2.00	19.0
19	13537	2.54	24.2
25	14005	3 60	35.3
17	14323	4.60	43.8
23	14733	6 26	59.7
47	13874	2.60	24.8
46	13014	1.15	10.95
73	11649	.649	6.18
163	8601	.169	1.61
129	6189	0	0

TABLE XXXI.

Ring I.			Ring II.			Ring III.			Ring IV.		
$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$
15065	12198	66.9	15624	11207	61.3	16053	9890	65.0	14753	6189	59.7
12689	10536	31.0	13855	10617	34.4	14545	9743	36.2	10892	5975	8.49
10205	8197	22.2	11031	8923	18.9	10066	8446	15.6	7837	4825	3.54
6231	4347	18.35	7932	6350	12.74	9032	7231	11.25	3552	1748	1.14
3167	1615	15.5	4616	3388	9.5	6357	4906	7.8			
932	186	8.68	1852	1000	6.89	4811	3670	6 00			
			803	276	4.81	9668	1766	4.38			
						530	153	2 28			

K. Annealed.

TABLE XXXII.

Ring I; $n_1 = 300$; $c = 127$; $\mathfrak{B} = 21.5 \times d$; $\mathfrak{H} = 9.54 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+6751	0	0
115	4278	.500	4.77
77	2623	.66	6.3
133	− 2237	.88	8.4
181	4128	1.331	12.7
128	6880	2.00	19.1
67	8321	2.52	24.0
95	10363	3.62	34.5
60	11653	4.62	44.1
75	13266	6.42	61.2
45	12298	3.81	36.3
101	10127	1.57	15.0
52	9009	.89	8.5
45	8041	.45	4.29
60	6751	0	0

TABLE XXXIII.

Ring II; $n_1 = 300$; $c = 127$; $\mathfrak{B} = 23.5 \times d$; $\mathfrak{H} = 9.44 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+10838	0	0
99	8313	.190	1.79
147	4565	.265	2.50
230	− 1810	.370	3.49
146	5533	.500	4.72
94	7930	.660	6.23
71.5	9753	.878	8.29
74	11640	1.328	12.55
50	12915	2.00	18.9
24	13527	2.50	23.6
33	14569	3.60	34.0
20	14879	4.60	43.4
25	15590	6.30	59.5
27	14841	3.78	35.7
42	13770	1.55	14.63
31	12980	.745	7.03
27	12419	.418	3.95
62	10838	0	0

TABLE XXXIV.

Ring III; $n_1 = 300$; $c = 127$; $\mathfrak{B} = 18.8 \times d$; $\mathfrak{H} = 9.52 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+10105	0	0
85	8507	.110	1.05
84	6928	.170	1.62
212	2942	.230	2.19
149	272	.27	2.57
262	− 4635	.371	3.53
158	7005	.506	4.81
99	9469	.669	6.37
78	11032	.888	8.36
82	12474	1.349	12.84
56	13597	2.10	20.0
98	14053	2.59	24.6
38	14767	3.75	35.7
93	15190	4.84	46.0
31	15789	6.8	65.0
35	15124	3.99	38.0
53	14128	1.60	15.23
35	13470	.885	8.43
32	12868	.550	5.23
147	10104	0	0

TABLE XXXV.

Ring IV; $n_1 = 300$; $c = 127$; $\mathfrak{B} = 19.0 \times d$; $\mathfrak{H} = 9.52 \times I$.

d	$\mathfrak{B}$	I	$\mathfrak{H}$
—	+6764	0	0
143	4047	.055	.53
222	− 171	.085	.84
140	2831	.116	1.10
142	5529	.182	1.73
69	6840	.258	2.45
54.5	7870	.365	3.47
37.5	8588	.500	4.76
28.5	9130	.66	6.28
25	9605	.876	8.34
29.5	10165	1.322	12.68
22	10583	1.95	18.6
32	11191	3.55	33.8
33.5	11828	6.10	58.1
44	10092	2.54	24.2
27	10479	1.278	12.19
20.5	10089	.762	7.44
21	9690	.508	4.84
48	8770	.200	1.9
28	8056	.09	.86
68	6764	0	0

TABLE XXXVI.

Ring I.			Ring II.			Ring III.			Ring IV.		
$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$
13266	6751	61.2	15520	10838	59.5	15782	10105	65.0	11828	6764	58.1
10498	6343	36.3	13490	10277	23.6	14645	9926	35.8	10298	6802	12.43
8546	5686	24.0	10296	8237	8.30	12446	9475	12.8	8854	6403	4.73
5278	3795	12.8	7319	5840	4.72	9673	7830	6.28	6970	4931	1.74
3064	2118	8.48	5317	4066	3.49	6514	5349	3.51	4636	3610	1.12
1866	1178	6.37	2754	1811	2.50	4933	3149	2.50	3268	2508	82
537	193	3.53	1033	446	1.79	2613	1871	2.27	665	247	.52
						1150	686	1.61			

L. Re-annealed.

TABLE XXXVII.

Ring II.			Ring III.		
$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$	$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$
14813	7717	61.0	15517	9507	59.0
13611	7691	35.9	13438	9209	18.2
10993	7274	16.85	10943	8259	8.08
8615	6085	8.69	8240	6615	4.39
7033	5161	6.14	6509	5307	3.36
3605	2543	3.21	3969	3005	2.39
936	405	1.89	2552	1843	2.0
			1087	633	1.48

TABLE 1A.

Ring I.		
$\mathfrak{B}_m$	$\mathfrak{B}_r$	$\mathfrak{H}$
13847	7966	61.5
13315	7960	48.7
12180	7956	37.8
10120	7104	26.3
7119	5293	16.2
3637	2481	10.9
1425	724	7.1

The hysteresis curves show strongly the influence of carbon, the area of the loops diminishing with the decreasing percentage of carbon. The mild steel shows, indeed, a curve very similar to that of wrought iron. The maximum induction, taking the rings in the order I, II, III, has the values: 13840, 15070, 15290 lines of magnetic force, while the magnetizing force was very nearly the same in all cases. The corresponding coercive forces are 8.6, 2.7 and 3.6.

B. *Rings heated to 675° and quenched.*—The rings were then introduced into furnaces, which were well heated beforehand. On the bottom of the muffles was put a sheet of asbestos and over this two strips of the same material, on which the ring was placed. In order to prevent oxidation as much as possible, charcoal was put in the opening of the muffle. The heating to a dull cherry-red took about eight minutes. Then the ring was withdrawn quickly and quenched in water at 5° C.

Ring I has become magnetically harder, *i. e.*, the maximum induction for the same magnetizing field has decreased, the permeability, especially for low fields, is smaller, and the coercive force increased to more than twice its original value.

The iron ring shows an increase in permeability, which may be explained by a previous mechanical hardening, when it was turned to its proper shape.

In rings II and III there is no sign of magnetic hardening, the principal influence of this treatment being the remarkable drop of the remanence, while the maximum induction remained almost unchanged. The permeability, on the other hand, decreased a little. This sudden and unexpected drop in retentivity will again be met later on and discussed there more fully.

It is apparent that we have not passed the temperature at which low carbon steel is hardened. It is well known that the second and third point of recalescence for low carbon steel lie at a higher temperature than the corresponding point in the high carbon steel, which apparently had already been passed in the case of the high carbon steel. It is, therefore, probable, though I do not consider this experiment as an absolute proof, that the magnetic hardening takes place when steel is quenched after it has been heated to the same temperature at which recalescence occurs, *i. e.*, the critical temperature, at which, according to Hopkinson and others, iron loses its magnetic properties.

C. *Rings heated to a little above* 900° *and quenched in ice-water of* 5°.—The heat treatment was the same as in B, but the temperature was raised beyond the third point of recalescence of the low carbon rings.

All the steel rings show the hardening effect, the same being the smaller the less carbon the steel contained.

The high carbon ring (I) shows a decided increase in the hysteresis loss, which is much greater than the increase due to the first heating. While the first time the temperature was raised only a little beyond the point of recalescence, it was this time at least 250° higher. *We draw therefrom the important conclusion that steel becomes magnetically the harder, the more the temperature is raised beyond the recalescent point.* The passing of this point by only a few degrees is not sufficient for the maximum effect.

The hysteresis curves for the steel rings are given on Figs. 1–3, the maximum induction ($\mathfrak{B}_m$) and remanence ($\mathfrak{B}_r$) as a function of the magnetizing force on Fig. 4, and $\mathfrak{B}_r$ as a function of $\mathfrak{B}_m$ on Fig. 5.

D. *Rings reheated to* 100° *for one hour.*—The corresponding curves are marked by crosses on the plates and are drawn only

for the low carbon rings, the change being very small for the high carbon steel. The influence of this step becomes more apparent the less carbon the steel contains, and *it consists in a lowering of* $\mathfrak{B}_m$ *as well as* $\mathfrak{B}_r$ in Rings II. and III., and in a slight raising of the same quantities in Ring I. The coercive force in III. has become slightly larger. *The low carbon steel becomes,*

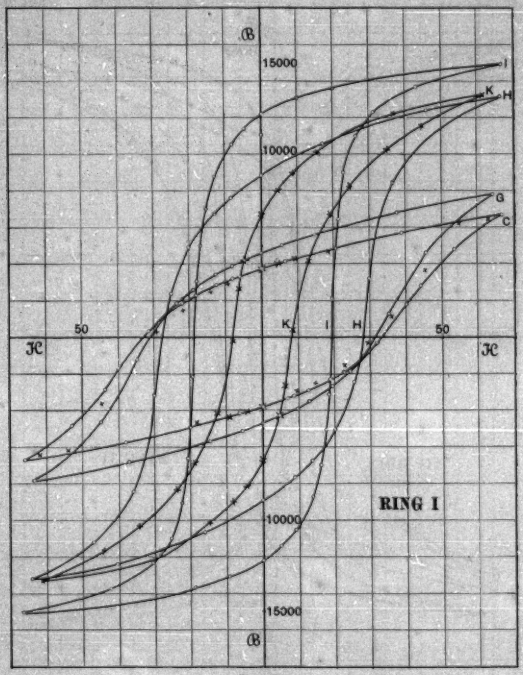

FIG. 1.

therefore, magnetically harder when it is reheated to 100°. This result is consistent with the observations of Barus and others, mentioned above.

E. *and* F. *Rings were heated to* 100° *for* 24 *hours.*—The heat treatment was the same as in the preceding case, except that the time of the heating was increased. I do not give the results,

since no decided change takes place. The curves almost coincide with the preceding ones, though there is an unmistakable increase of permeability, especially for small magnetizing fields, this change being largest for the high carbon steel. We have, therefore, a more or less pronounced influence of the time during

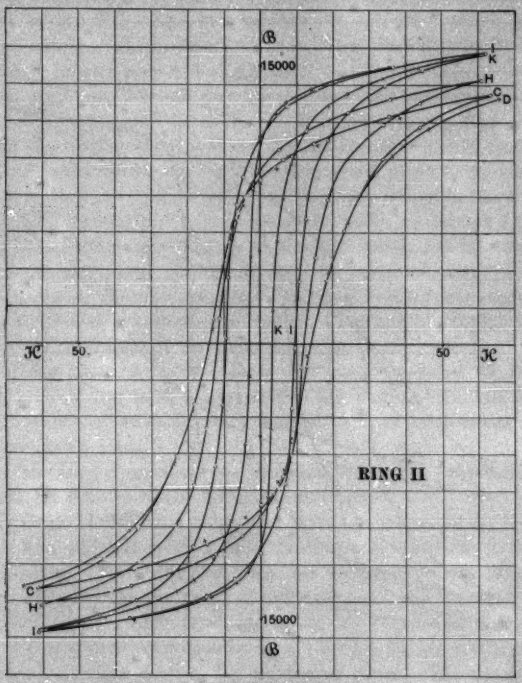

FIG. 2.

which the rings were subjected to this temperature, consisting in a slight increase of permeability.

6. *Rings reheated to* 200°.—Apparatus for the heat treatment: On the top of the heating table were placed two strips of asbestos, on this a disk of the same material with a round hole in the middle, then a layer of iron turnings and on this the ring. The

whole was surrounded with an asbestos ring, which was filled with iron turnings, so that the ring was entirely imbedded in the same. The temperature was read by means of a thermometer, which was placed so as to touch the ring inside. By the arrangement described, uniform distribution of heat from the centre was

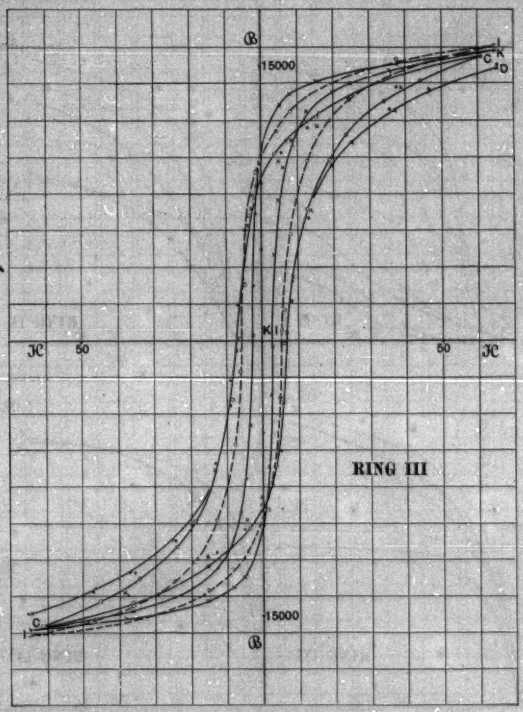

FIG. 3.

procured. As soon as the temperature rose to 200° the ring was withdrawn and allowed to cool in the air.

I give the results for Ring I. only, the others showing a very small increase in magnetic induction.

We will see from the comparison with the data given later on

that the increase of induction is comparatively small in all rings.

H. *Rings reheated to* 300°.—The heat treatment was practically the same as in G.

All rings show a decided increase in permeability, the change

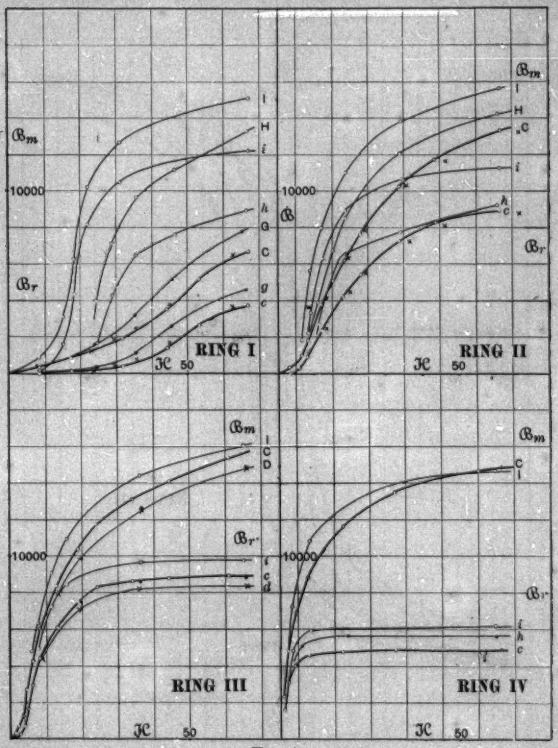

FIG. 4.

being the smaller the less carbon the steel contains. The curve for Ring III., indeed, coincides so nearly with that of the hardened ring that the points corresponding to this step could be indicated only by dots in the plates. The wrought iron ring, that so far showed no sign of a change, has a larger permeability for small

fields than it had before. By comparing the curves on Fig. 4, we see a decided tendency towards an increase of the remanence for any given value of maximum induction. This will become more and more decided as we increase the temperature to which the rings are reheated.

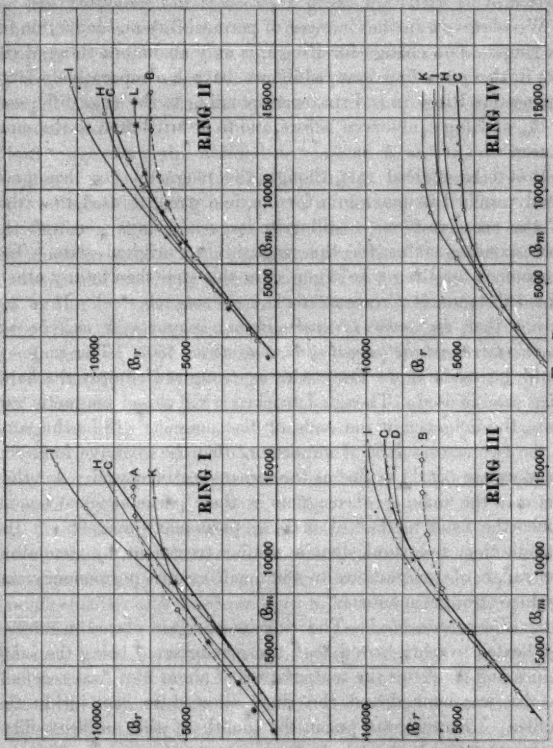

FIG. 5.

The most important and rather unexpected result of this step is the sudden very large increase in the maximum induction of Ring 1. The number of lines of magnetic force has almost reached the value the ring had before it was heated at all. Therefore, whatever change in the chemical or physical consti-

tution of the ring produces the change in the magnetic properties, it is largest for the high carbon ring between 200° and 300°, *i. e.*, at a temperature which corresponds to that of the blue temper of steel.

I. *Heated to* 450°.—Heat treatment was practically the same as in G.

We observe a further increase of permeability and induction for all rings. The change for Ring I. is only about one-third of the one in the preceding case, while we have a comparatively large change for Rings II. and III., corresponding to the large difference in $\mathfrak{G}_m$ of Ring I., observed before, and to be attributed to the same causes.

It is to be noticed that, though the magnetic flux has practically reached its maximum for the field strength used, the value of the coercive force is still quite large in comparison with the corresponding value for the rings in the original state. The remanence for Ring I. is larger after this step than in any other. The substance is Crescent steel, *i. e.*, magnet steel. It is apparent that, *in order to make strong magnets, it will be advisable to reheat the quenched steel to about* 450°. The magnets could be made more than twice as strong as if simply the hardened steel is used. Though I worked with closed magnetic circuits, the influence of the ends of the magnets will be the same in the two cases. It is of importance that the coercive force did not decrease nearly as fast as the remanence increased. Another factor in the making of magnets is their permanency. I mentioned the usual method of making permanent magnets in the introduction, and think that a similar treatment, by extending the range of temperature to 450°, will ensure permanency and produce stronger magnets.

K. *Rings annealed.*—The rings were again placed in muffles and heated to a bright red heat, the arrangement being the same as in B and C. After the temperature of about 850° was reached, the fire was banked and the rings allowed to cool inside the muffles. Charcoal was put in the mouth of the muffles. This treatment took about 24 hours.

The rings have become magnetically soft. While in the Rings II. and III. the saturation point was practically the same as before, the coercive force decreased to its smallest value, this last step being the largest in the whole series for the coercive force.

In the high carbon steel and the wrought iron, we find a re-

markable decrease in $\mathfrak{G}_m$, accompanied in Ring I. by a still greater decrease of $\mathfrak{G}_r$, while in the iron $\mathfrak{G}_r$ increases with respect to $\mathfrak{G}_m$. These changes can very plainly be observed on Fig. 5, where $\mathfrak{G}_r$ is plotted as a function of $\mathfrak{G}_m$. The curve obtained for Ring I. differs entirely from any of the curves taken after the ring was hardened, but it shows a great similarity to curve A taken in the original state.

Hoping to obtain similar curves for the other two steel rings they were again annealed, the temperature this time being raised to nearly 1000°. Cooling took place in the same way as before.

L. *Reannealed.*

Both rings show the decided decrease of $\mathfrak{G}_r$ and the different character of the curve. The one for Ring III. is indicated by dots only, and coincides partly with curve I. In both cases there is a great similarity with the curves B, obtained by heating the originally annealed steel to a high temperature below the point of recalescence and suddenly quenching. It almost seems that the steel by this process has become a different substance. These curves show more the characteristics of the iron (see ring IV. on Fig. 5) than of steel. Houston and Kennelly's law does not hold for nearly as wide a range as before. I believe that the effect observed in the last step is not an immediate effect of annealing, but that it is the conditions under which cooling takes place, that influence largely the retentivity of steel.

Steel heated to a high temperature below the point of recalescence and suddenly quenched as in B, *will very easily lose its magnetism.* This seems to me of practical importance. The maximum induction being the same, and the remanence a great deal smaller than in the ordinary state, it is apparent that the hysteresis loss will be much smaller, and therefore very mild steel, as our Ring III., treated in the way indicated above, is preferable to the ordinary mild steel used in transformers or other instruments, in which cyclic processes take place, if the induction is carried to high values.

Since the hysteresis loss has been found to increase appreciably in transformers after they have been used for some time, it is of great importance to investigate whether a similar effect takes place in steel treated in the manner suggested. A series of such experiments would be very valuable from a practical point of view.

In 1890, Osmond (*Phil. Mag.* 29, 511, 1890) advanced a theory according to which a bar of steel consists of an intimate mixture of α iron (magnetic) and β iron (unmagnetic). He considers the β modification as forming in a steel a porous framework, the ratio

between the amount of α iron and β iron not changing under the influence of currents and of magnets. "In the presence of the rigid network of β iron the polarized α particles are conceived as catching in the pores of the β structure and immovable in this position, thus resulting in a permanent magnet." Moreover, he supposes the temporary induction and the remanence to be a function of the ratio $\frac{m}{n}$, where m is the percentage of α iron, and n the percentage of β iron in the steel. Let mp and np (Fig. 6) represent the corresponding values; then the maximum induction is proportional to mp, the residual to mr. Further suppose, that the fraction of the maximum induction forming the remanence (r) is proportional to the amount of β iron (n); he then derives the formula

$$r = K\left(m - \frac{m^2}{100}\right) = K\left(x - \frac{x^2}{100}\right)$$

Consequently the remanence is represented by a parabola starting from O upward and meeting the X axis at a point corresponding to 100% α iron.

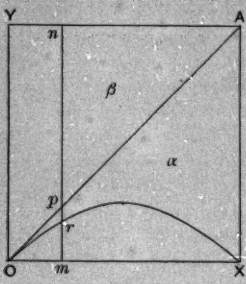

FIG. 6.

Suppose this theory to be correct, then by a change of β iron to α iron the difference between the maximum induction and the remanence increases. My experiments show that this does not take place by reheating the hardened steel. (Compare results represented on Figs. 4 and 5.) On the contrary, the difference becomes smaller. We cannot assume a transformation of α iron to β iron, since the permeability increases decidedly on reheating. On the other hand, the sudden drop of the remanence observed before the point of recalescence is reached, would correspond very well to Osmond's theory, if we suppose a transformation of β to α iron has taken place.

I believe that we have also to take the influence of the carbon compounds into account, which has not been done by Osmond. Let us assume that the reheating has such an influence on the iron in the iron ring and on the carbon compounds as to decrease the relative distance (Fig. 6) between the maximum induction and the remanence, and that the rate of this change decreases, the higher the temperature to which the rings are reheated. Probably

the process producing this change, whatever its cause may be, is completed at high temperatures. If besides this there is any other influence present producing a relative drop of the remanence as should be expected from Osmond's theory, when not α iron changes to α iron, this latter effect is masked at the beginning by the effect mentioned first, but it becomes more apparent the higher the temperature and the smaller the change connected with the relative increase of the remanence. Finally at still higher temperatures only the influence of the transformation of non-magnetic iron to magnetic iron remains, the other process being practically completed.

Figs. 4 and 5 show that, while in the iron ring in which there is no β iron, only the first influence can be observed, we have both effects in the steel rings; here the second influence does not appear, until we have almost reached the point of recalescence, and it is the more prominent, the harder the steel or (with Osmond) the more non-magnetic iron the steel contains.

The results of this research may be summarized as follows:

1. The point at which steel becomes magnetically hardened by quenching, lies at different temperatures, according to the amount of carbon contained. It is considerably lower in high carbon steel than in low carbon steel, and corresponds closely to the different temperatures at which recalescence occurs.

2. The higher above the point of recalescence steel is heated before being quenched, the harder it is magnetically.

3. The magnetic hardening produced by quenching is the larger, the higher the percentage of carbon.

4. Reheating has in general a softening effect upon the magnetic properties of hardened steel, *i. e.*, the permeability increases, and is accompanied by an increase of maximum induction and a decrease of the coercive force. But a hardening is noticeable in the low carbon steel after it has been reheated for a short time to 100°. The greatest change in the maximum induction takes place for high carbon steel between 200° and 300°, for low carbon steel between 300° and 450°, beyond which temperature there is hardly any change in the practical limit of saturation. All change taking place in reheating beyond 450° consists in an increase of permeability for small magnetizing forces, *i. e.*, a decrease in the coercive force or hysteresis loss.

5. To produce strong magnets, the hardened steel should first be reheated to 450°.

6. Heating to a high temperature below the point of recalescence and sudden quenching, produces a steel with a very weak retentivity if the value of the magnetizing force has been large; in consequence of which the hysteresis loss in a cycle is greatly decreased. This result may also be obtained, though in a lesser degree, by annealing at a very high temperature.

I am greatly indebted to Mr. L. F. Morehouse, one of my students, for the valuable assistance rendered me in most of the experiments.

Physical Laboratory of the University of Michigan.
March 13th, 1897.

Discussion.

Prof. Henry S. Carhart:—*The Bearing of this Investigation on the Theory of the Constitution of Steel.* The chemical composition of the steel and iron, whose magnetic properties Dr. Guthe has investigated, has been carefully determined. This was done because one of the chief objects in view was the bearing of the magnetic properties of steel and iron on the theory of their composition. The theory of steel has been studied by means of chemical analysis, by its microstructure and by its mechanical and magnetic properties. Dr. Guthe's paper connects the first method and the last two.

The old carbon theory of the hardening properties of steel and its corresponding changes in magnetic properties, has been strongly opposed by the most recent allotropic theory, of which Osmond, of Paris, and Roberts-Austen, of London, are perhaps the most conspicuous supporters. This theory appears to be based on the known chemical and structural changes which the carbon undergoes when the metal is raised to high temperatures, and on the recalescence or retardation points of iron.

Osmond distinguishes three allotropic forms of iron, which he calls α iron, β iron, and γ iron respectively. For the present purpose we need to distinguish between the α and β forms only. The α iron is magnetic, the β form non-magnetic.

The first point of recalescence, or of the retardation which iron exhibits either in the process of heating or of cooling, is from 640° to 690° C. Below this temperature, annealed low carbon iron consists almost entirely of α iron. The point of retardation of the temperature on cooling is about 30° lower than on heating, or the iron exhibits another characteristic form of hysteresis. Iron containing more than about 0.5 per cent. of carbon has only this first point of retardation. It is denoted by A_1.

The second retardation point in low carbon iron, called A_2, occurs at temperatures between 700° and 750° C. Iron having less than 0.5 per cent. carbon and more than 0.25 per cent. exhibits this second point of retardation in addition to the first.

The third point, denoted by A_3, lies between 800° and 850° C. Iron containing less than 0.25 per cent. of carbon has all three points of retardation in heating and in cooling slowly.

When carbon is present in sufficient amount, it has the power of lowering the temperature of both upper points of retardation to that of the first, so that high carbon iron exhibits only the one point.

At these points of retardation, iron changes its allotropic form and these changes are accompanied by changes in the chemical composition of the carbide of iron and its distribution or diffusion through the mass of the iron. Such allotropic changes correspond to a critical change of energy. The passage of iron from one allotropic form to another is attended with evolution or absorption of heat. Professor Roberts-Austen defines allotropy as follows: "Allotropy is a change of internal energy in an element at a critical temperature, unaccompanied by a change of state." When iron is heated to the point A_1, the heating is temporarily arrested with more or less suddenness, and heat is absorbed. On lowering the temperature, the cooling is arrested at a sensibly lower temperature, and heat is evolved.

During these allotropic changes on heating, energy is absorbed at the critical points, as the metal passes from a more stable to a less stable condition. When it cools slowly, the stored energy is given up again at the corresponding points of retardation on the curve of cooling, as the iron reverts to its more stable form. But when steel is suddenly cooled by quenching, Osmond and Howe have shown that there is no point A; or, in other words, the iron exhibits no retardation, and retains the energy absorbed at the retardation points on the curve of heating. It is then assumed that other properties above the critical range of temperature are retained along with the absorbed energy. In general, the heat of combination of quenched steel is appreciably larger than that of the same steel which has not been hardened by quenching. Some anomalies in this branch of the subject, however, await a satisfactory explanation.

Sauveur has recently shown by microscopic examination, that a marked structural change in steel accompanies the allotropic change at each critical point. These "changes of structure," he says, "correspond exactly with the retardations, beginning and ending with them." Within ranges of temperature not containing any critical point, there is no change in the microstructural composition of steel. It is, therefore, not unreasonable to conclude that the energy changes which occur at the retardation points are due to the structural changes themselves. This view is supported by the fact that soft iron ceases to be magnetic, according to Tomlinson, at 950° C., the highest retardation point on heating; low carbon steel at 750° C., the second critical point; and high carbon steel at 650° C., the lowest critical point.

Analogous cases of energy change, accompanying a change in physical state, are that of ice absorbing energy when it passes into

a liquid, and sodium sulphate, for example, evolving heat when it passes suddenly from a saturated solution into a mass of crystals.

It remains to be determined whether these critical changes in iron are physically or chemically allotropic, or perhaps both; for if the word compound be used instead of element in the definition of allotropy, it will then include cases of isomerism.

The allotropic theory is founded on these energy changes which carburized iron undergoes when it is heated or cooled; it considers carburized iron as an alloy, and this alloy may be dissolved in the pure iron or ferrite. "The presence of 0.9 per cent. carbon marks a saturation-point of iron by carbon." It is also a fundamental hypothesis in the allotropic theory, that carbon hinders the change of non-magnetic β iron back to the magnetic α form, even during slow cooling. When the hot iron is suddenly quenched, the iron remains largely in the β form, if much carbon is present.

Since α iron is magnetizable, temporary magnetism consists in the setting of the magnetic axis of the α particles more or less completely in the direction of the axis of magnetization. In-so-far as the particles retain this polar arrangement, the magnetism is permanent. Now the inert β iron is supposed to act as a viscid matrix encasing the magnetic particles. It therefore renders it more difficult of magnetization, and for the same reason restrains the α iron particles from returning to their unmagnetized relations to one another. Hence temporary magnetism increases as the relative quantity of α iron increases, while the relative value of the remanence increases with the β iron.

Since carbon is assumed to check the conversion of β iron in cooling to α iron, high carbon iron when hardened is more difficult to magnetize; but on the other hand, when it is once magnetized, it retains it magnetism with greater tenacity than low carbon iron does. In a mixture of α iron and non-α iron, the latter entangles the other and acts as a passive obstacle to the magnetization of iron; it also helps to retain it when once magnetized. Hence the presence of non-magnetic iron is offered as a sufficient explanation of remanence.

In support of the theory that iron undergoes allotropic changes it may be mentioned that iron entirely free from carbon, exhibits the two upper retardation phenomena. The change associated with them is therefore a physical or allotropic one, and is not dependent on carbon. On the contrary, the lowest point of retardation is identified with a change in the carbon; and within limits, the retardation is more pronounced as the percentage of carbon increases.

Again, Beetz found that when pure iron was deposited electrolytically in a thin line on silver parallel to an intense magnetic field, it was permanently magnetized and no more magnetism could be induced in it. Here carbon plays no part in the mag-

netic phenomena, and besides it is difficult to see how any of the theoretical non-α iron can be present.

Manganese steel presents difficulties for the allotropists. According to the allotropic theory, this steel is hard and non-magnetic on account of the preponderance of β iron. But it is quite possible to give to manganese steel, magnetic properties without diminishing its hardness. Hence it furnishes no proof of the presence of β iron.

Further, an alloy containing 25 per cent. of nickel exhibits remarkable properties. Dr. J. Hopkinson has shown that this alloy is magnetic or non-magnetic, according to the heat treatment it receives. In the non-magnetic form it should therefore be hard, and should contain a very large proportion of iron in the β form. But it is equally soft and can be readily machined in either condition. How then can the allotropic theory explain why manganese steel may become magnetic without losing its hardness, and nickel steel become non-magnetic without losing its softness?[1]

Dr. Guthe has demonstrated that high carbon steel must be heated to a temperature above the lowest retardation point before it is hardened to any considerable extent by quenching, and before it exhibits marked retentivity. The lowest retardation is thus identified with the change in the magnetic properties of steel produced by quenching and hardening.

He has also shown that the remanence is proportionately larger, the higher the steel is heated above the lowest point of retardation. Sudden cooling above A_1 is necessary to enable the iron to retain its magnetism. If it is quenched near A_1, much of the iron may cool below A_1 before it is really chilled. To secure more thorough chilling, it must be quenched from a higher temperature. In terms of the allotropic theory more of the β iron is retained in that form if the temperature is high enough to secure chilling before the iron fails to the point A_1.

With low carbon iron, heating to about 650° and quenching actually reduces the remanence and the coercive force some 25 per cent., as shown by Ring III. Ring I. shows that tempering increases not only $\mathfrak{B}_m$, but $\mathfrak{B}_r$ as well. Further, the same ring has both $\mathfrak{B}_m$ and $\mathfrak{B}_r$ reduced by annealing. It is difficult to see in what way the allotropic theory can account for these results.

In contrast with Rings I., Rings III. and IV. show on annealing an increase in the value of the remanence as compared with $\mathfrak{B}_m$.

Again Fig. 4 shows that the remanence, as a function of $\mathfrak{C}$, increases as the process of annealing is carried farther and to higher temperatures. It is difficult to reconcile this fact with the allotropic theory, especially with soft iron rings where the proportion of non-α iron to α iron must be small.

If the allotropic theory is correct, then a transformation of β

1. *Trans. Amer. Inst. Mining Engineers*, R. A. Hadfield.

iron to α iron must be accompanied by a decrease in the remanence or residual magnetism, as compared with the maximum induction. This is apparent from an inspection of the diagram in Osmond's theory. Now in the process of annealing β iron reverts to α iron. It will be seen, however, that while in Rings I. and II. of highest carbon, the ratio of $\mathfrak{B}_r$ to $\mathfrak{B}_m$ decreases as the annealing progresses, the reverse is true with Rings III. and IV. In the step B, however, there is a reduction in the remanence as compared with the maximum induction.

In high carbon steel non-α iron is supposed to revert to α iron at the temperature of the first point of retardation. But Dr. Guthe shows that such steel exhibits a large increase in permeability when it is heated to a temperature between 200° and 300° C. This temperature is much below A_1. Does then non-magnetic iron revert to magnetic iron at this comparatively low temperature? If so, what connection has this magnetic change with the allotropic changes on which the theory is supported?

All existing physical theories of magnetism now recognize that the particles of iron are always magnets. Ewing's beautiful theory and the experiments supporting it are in harmony with the physical phenomena. There is no place in this apparently for non-magnetic iron, and none for the easy passage of iron from the magnetic to the non-magnetic state or the reverse.

Osmond admits that magnetic phenomena come with difficulty into line with the allotropic theory. It is pertinent to raise the inquiry whether some of the facts brought out in Dr. Guthe's paper are not irreconcilable with this theory.

Mr. Paul A. N. Winand:—I would like to remark that the temperature at which the bar has been heated above the critical point, has something to do with the suddenness with which the various parts of the cross-section will cool down past that critical point; because, if we are just above the point to start with, the particles nearer the centre will cool rather slowly at first. They will gradually take a faster rate of cooling, but by the time the rate of cooling has become sufficiently rapid, the temperature of these points has dropped below the critical degree and they fail to become magnetically hard. But if we are pretty well above the critical degree to start with, the whole cross-section will pass pretty suddenly through that degree; and it is perhaps not the fact that the steel was heated at a high temperature, but simply the special circumstance that it was cooled more quickly past the critical degree, which accounts for the difference mentioned in the paper.

My friend Billberg and myself once tried to magnetize bar-magnets by quenching them while they were subjected to the magnetizing force, in order to see whether we could get any better magnets, and there seemed to be a slight difference in favor of this course. We made the measurements only roughly, because we wanted to see if there would be any important gain. The gain did not seem to be sufficient to warrant for the trouble,

so we did not try any further in this direction. It may be, however, that some results could be obtained by careful measurements that would throw some light on the subject generally.

Perhaps it would be necessary to employ a very high magnetizing force at the high temperature, as the steel is hardly magnetic at those temperatures. We did not employ a magnetizing force any greater than what seemed to be amply sufficient to magnetize the cold bars to the highest point attainable.

Mention was made by Prof. Carhart of the behavior of a thin film of electrolytically deposited iron which showed permanent magnetism if deposited in a strong field. At high temperatures the material might behave in a similar manner, provided the field be strong enough

THE CHAIRMAN [Vice-President Pupin]:—I may say that the paper is so exhaustive that it is very difficult for any member present to make up his mind in the course of one evening as to the correlation of facts disclosed in this investigation. There is perhaps no phenomenon that is so complex as the magnetization of iron. I remember that Helmoltz in his lectures at Berlin when I was a student there, whenever he came to discuss the behavior of permanent magnets in a varying electromagnetic field, used to stop and make a very long pause and then finally, at the end of the pause, he would say: "When we come to permanent magnets, then I don't know whether this question holds true or not." It was a sort of stumbling block in his analysis of the forces which come into play in a varying electromagnetic field. I could not help thinking that in the phenomena which Prof. Carhart described to us, the molecular forces have a great deal to do with the behavior of magnetized iron. Wherever we have a close connection between the changes in the temperature of a substance and the forces the seat of which is in the substance, we may be pretty sure that those forces depend on the molecular state of the substance; because, according to our view of temperature, it is something which depends on the molecular and not on the atomic state of the substance. There is no doubt that these sudden changes in the behavior of the retentive force, the coercive force caused by a sudden change in the molecular structure. But how close this relation is, it is very difficult to tell. I am rather in favor of the view that these sudden changes in the retentive and coercive force and permeability, are accompanied by an allotropic change in the structure of the substance. Of course, that is only a matter of feeling; and, as I said before, the number of facts brought out by this investigation is so large, that it is very difficult to co-ordinate them and form a consistent physical theory in the course of one evening. We have to be guided more by feeling than by reasoning. I don't know but that such perhaps is the course which we have to pursue in the study of the magnetic literature. Take, for instance, Ewing's book and read it; when you get through it you say, "I have got to read it again."

You read it again, and after reading it the second time you have very probably changed your first view, and so the third or fourth time—every time you read it you seem to change your opinion. Lay the book aside, and after about four or five or six months, you feel that your whole knowledge of the facts disclosed in the book is retained in your heart and not in your mind. It becomes a matter of feeling, and not of pure reasoning, and that is the surest sign that the correlation of facts is in a sort of nebulous state, and I think that being in a nebulous state as it is, it is the more interesting. Because when a part of a science is perfectly elaborated and worked out so that there seems but little left to be done, then it is like a garden laid out by a landscape gardener—one likes better to walk in a place where there is something to improve. The investigation described before us this evening invites us into a field which is a very promising one and a very interesting one, although some people seem to think that there is nothing less interesting than a permanent magnet, because a permanent magnet is permanent, and that is all that there is to it. But that is not so, because there is more difference between one permanent magnet and another than there is between any other two things of the same kind. We may congratulate ourselves that the subject has been taken up by so competent hands as those of Professor Carhart and his associates, and I am sure that it is going to remain in good hands and give us much needed information.

MR. NELSON W. PERRY:—I think we are greatly indebted to Dr. Guthe for his paper—probably a little too deep for most of us to discuss off-hand. We are also greatly indebted to Professor Carhart for presenting it in such an admirable manner, and I move that a vote of thanks be tendered to Dr. Guthe for his paper and to Professor Carhart for his kindness in presenting it and for his own remarks upon the subject.

[The motion was carried. Adjourned.]

[COMMUNICATED AFTER ADJOURNMENT BY PROF. ELIHU THOMSON.]

The valuable paper of Dr. Guthe calls attention to the need of accurate knowledge concerning the behavior of steel as a magnetic medium when it has been treated by heating, quenching, cooling and annealing or tempering. Incidentally some of the considerations are shown to apply to those varieties of iron containing such low amounts of carbon as not properly to be called steel, except in relation to the process used in making them. The subject is one of great practical importance and it is only by such experimental data as the paper furnishes that we can advance.

Nearly ten years ago my attention was strongly drawn to the problem of producing permanent magnets for magnetic dampers of meters. There was but little information to be had on the

subject, either as to the nature of the steel to be used for the best results, or the methods of treatment, hardening, tempering, or the like to be employed.

This led to the carrying on through several years of thousands of experiments, and the development of methods of rapid measurement of the flux between the poles of the magnets, as well as methods of heating, forming, hardening, tempering, seasoning and testing for permanence. Very many analyses of different steels were also made, with the object of discovering the effect of the differing proportions of carbon, tungsten, silicon, etc. I notice that Dr. Guthe has not included a ring of tungsten steel now almost universally used for magnets, among those subjected to test. In our work we soon found that no steels without tungsten gave such relatively high induction together with other desirable qualities, as steel containing two to three per cent. of tungsten. Amounts up to four or five per cent. of tungsten gave no advantage, while with less than about two per cent. the induction fell off and the metal approached ordinary steels in magnetic qualities.

It was found that the treatment recommended by Barus and Strouhal for seasoning, and referred to by Dr. Guthe, was not sufficient to ensure permanency even where the form of the magnet was, as in our meter magnets, quite favorable to retention of magnetism.

The effect of heating to 100° C. for several hours, caused a loss or diminution of flux which varied with the composition and prior treatment of the steel. Extending the time of the heating to twenty-four hours or more, gave scarcely more effect than an hour or two. The object was, of course, to reduce the flux to that amount which the steel would retain permanently. In the course of this work it was determined that repetitions of the heating to 100° C. after cooling would cause a further loss of magnetism, but at each repetition the percentage became less so that there was at last no discoverable change. A magnet so treated is practically permanent at ordinary temperatures. Whether the effect obtained is due to the removal of that portion of the flux which may be considered as unstable or to a magnetic hardening was unknown, but it would appear from Dr. Guthe's paper that both effects may have been produced, assuming that tungsten steel behaves in the same ways as that of the rings tested by him.

We developed a process of seasoning magnets which consisted in subjecting them after hardening and magnetizing to successive immersions in boiling water and in cold water at intervals of a few minutes; a treatment carried on for a sufficient length of time to ensure stability of the flux density in the air-gap between the poles.

Certain facts alluded to in Dr. Guthe's paper have been known to us for a long time, and were developed in our practice. At

one time we arranged to temper our magnets after hardening, by heating them to temperatures just short of those giving the blue oxide coat. This was found to be a matter of difficulty in practice on the large scale, though it undoubtedly increased the induction. It was preferred to obtain a similar result by carefully excluding steels with too high a percentage of carbon, and by hardening the magnets by care in selecting the proper hardening temperature. Thus in fact the same principle was developed in our work as is alluded to by Dr. Guthe, namely, that too high temperatures of hardening give weaker magnets or those in which the steel is magnetically as well as mechanically harder and of too low magnetic susceptibility. It was in fact found that the desired flux could not be retained by such overheated steel when magnetized.

I think that the fact that with ordinary steels the strongest magnets are produced when the hardened steel has been heated to a blue, is well known, and has been practiced for a very long time by magnet makers. The magnets of the old magneto machines were nearly always blued. It has been my practice also for fifteen to twenty years to adopt a similar process in dealing with ordinary steel. After hardening, the brightened steel was carefully heated by a blow-pipe until the middle or neutral region of the magnet (bar or horseshoe) was blued, while the poles were kept of straw color, the one color fading into the other along the bar. A strong magnet is thus made and one which is relatively permanent.

The point made by Dr. Guthe that there is a proper temperature for annealing iron or mild steel in order to secure the greatest freedom from hysteretic loss has also been found to be the case in our practice with iron and steel. The range of temperature for the best effect is found not to be a wide one. Here again there is a widely known mechanical fact which bears upon the point under consideration. It is this, that some steels heated to that temperature which just fails to harden them, are on quenching made very soft. The range of temperature is narrow, but evidently has the bearing upon the recalescence temperature pointed out by Dr. Guthe. This may be observed by heating to redness one end of a bar and quenching it, when it will be found that just back of the hardened end is a very soft portion; noticeably so. It would appear probable that whatever softens the metal mechanically may have a similar effect magnetically.

It would take more time than is at my disposal to touch upon the many other interesting points brought out by Dr. Guthe's paper. I have alluded above to some of the more practical points useful to the constructor.

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